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William F. Schreiber
Professor of Electrical Engineering,
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Secretary, Federal Communications Commission
1919 M St.
Washington DC 20554

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Dear sir:

Enclosed are ten "original" copies of my Comments on the Notice of Proposed Rule Making released May 8, 1992 in MM Docket 87-268. Please provide an individual copy to each Commissioner.

Very truly yours,

William F. Schreiber
Professor of Electrical Engineering, Emeritus

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Before the Federal Communications Commission
Washington DC 20554

In the Matter of
Advanced Television Systems
and Their Impact upon the
Existing Television Broadcast Service

MM Docket No. 87-268
Second Report and Order/Further Notice of Proposed Rule Making
8 May 1992

Comments of

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The opinions expressed herein are those of the author only.

15 July 1992

Executive Summary

The conclusion of the Advisory Committee that the currently proposed systems adequately represent the state of the relevant technology, if ever correct, is so no longer. While the source-coding (compression) methods are highly developed, the channel-coding (transmission) methods are not. European digital-broadcasting technology, represented by orthogonal frequency-division multiplex (OFDM) and single-frequency networks (SFN), is in a far more advanced state than, and has many advantages over, the techniques used by the digital-system proponents. A terrestrial-broadcasting standard based on the techniques now being tested is likely to be obsolete before deployment, and to get further behind as extensive European work continues. With OFDM/SFN, only about 20 channels would have to be allocated to TV to provide up to 20 independent programs in each locality. Much cheaper receiving antennas could be used and reliability would probably be substantially higher.

To deal with this situation, it is proposed that knowledge about the European work be systematically disseminated in the US, that the system proponents be encouraged to cooperate in designing a system that would bring benefits to all the stakeholders in this matter, and that the ATTC have a much broader financing base.

Introduction

These comments are directed primarily at the question of whether the proposed ATV system now being tested adequately represent the state of technology so that a sound standards decision may be taken without reference to other possible solutions. These systems probably do represent the state of the art with respect to source coding (data compression) but they do not with respect to the equally difficult and important matter of channel coding, i.e., the delivery of the compressed data stream to the receiver. If there were adequate evidence that all system requirements would be met even if the systems did not take full advantage of recent advances in channel coding, then this matter could perhaps be overlooked. However, it is just in this area that the most serious questions exist. Even if the systems were to work precisely in the manner that the proponents have predicted, they would still fall far short of the spectrum efficiency that can be achieved by alternative solutions. In view of the general shortage of spectrum, (Indeed, this is the reason the current Inquiry was started.) getting the most service with the smallest spectrum allocation must be a high-priority goal of the Commission.

Since it is necessary to point out some shortcomings of the current proposals to make my point, I must emphasize the great respect I have for the results obtained in source coding by these systems. Few would have believed, three years ago, that something approaching HDTV could be produced at only 12 Mbits/sec. The problems with these systems are not due to lack of ability or effort on the part of the system designers; they are due to lack of resources resulting from the decimation of the US consumer-electronics industry. In addition, because of the requirement of testing in hardware only (even if this hardware is totally unrepresentative of the practical hardware that would be used in a real system), the competition has turned as much into a contest about each company's ability to mount crash programs as its ability to design television systems. Had the limited resources devoted to extremely complex one-of-a-kind hardware been directed instead toward improved channel coding, a much better result might have been produced.

Source Coding and Channel Coding

A complete system for capturing video information, transmitting it through a channel, and preparing it for display is shown in Fig. 1. A conventional video signal from a camera or production system is subjected to source coding, which results in a compressed data stream — digital, analog, or hybrid. The essential point is that the amount of information required to represent the scene before the camera is reduced. The channel coder prepares this data for transmission. It may take the form of an amplitude or frequency modulator in simple analog systems or can be a very complex device intended to mitigate the effects of channel imperfections. At the receiver, both of these processes are undone, normally resulting in a video signal much like that from the camera. This signal can be displayed on a TV picture tube or other device.

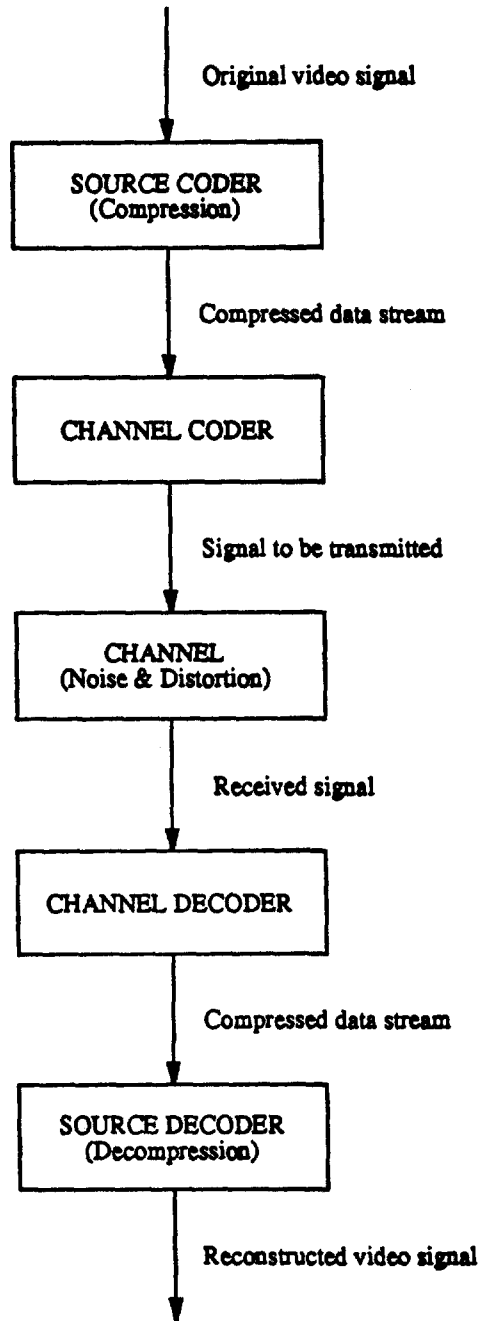


Fig 1. Video Transmission System

The channel coder is an essential element in all cases except where a direct wire path can be provided from source coder to source decoder, or where an error-free digital storage or transmission medium is used rather than a highly imperfect medium such as the terrestrial broadcast channel.¹ It is important to note that in today's NTSC broadcasting system, channel impairments such as noise, ghosts, and interference — not the bandwidth or resolution — set the effective limit to quality in typical homes. These impairments must be overcome to permit digital transmission at useful rates; digital transmission does not itself overcome channel impairments. If the impairments could be overcome, then NTSC studio quality would be achieved in homes using today's NTSC source-coding system, to the great satisfaction of viewers.² Unfortunately, NTSC's vulnerability to certain channel impairments is inherent. While ghosts might be greatly reduced, interference, which is largely responsible for the existence of taboo channels, could not.

Spectrum Efficiency

There are many system issues that cannot be settled by testing. For example, the simulcast decision already made was based on the perceived requirements of a viable system. Likewise, spectrum efficiency is a matter that must be decided on the basis of what kind of a system we need and want, in view of other claims to spectrum, such as cellular telephone service.

One way to make more spectrum available for mobile uses is to take TV off the air. Indeed, many digital enthusiasts have long advocated switching TV service to cable, DBS, and fiber. This solution appears to be unacceptable at present on both political and economic grounds.³ The free and universal service offered by the terrestrial broadcasters enjoys wide support among the public and in Washington. Terrestrial broadcasting is also a very inexpensive way to deliver broadband signals to the home, particularly since the system is already in place and paid for. The current controversy over who, if anyone, will pay for fiber to the home, makes it plain that the capital cost of providing universal service by any other transmission modality is a formidable obstacle to that solution.

If TV broadcasting is to remain on the air, the proper measure of spectrum efficiency is the number of channels that must be allocated to TV in order to provide a certain number of different programs of a certain technical quality to each viewer. At present, 68 channels are allocated and a maximum of about 20 channels can be used in each locality. The 48 channels that cannot be used represent the inefficiencies of the present system.⁴ The best possible system would require the allocation of only 20 channels overall. It is therefore of interest to see what happens to the

¹The error-free performance of digital storage and transmission systems actually is produced by a built-in channel coder invisible to the user. These systems nearly all use an analog medium, subject to some of the same kinds of defects as analog transmission channels. The necessary sophistication of the error-correction scheme depends on the properties of the medium and on the data density or data rate.

²In tests carried out at MIT's Audience Research Facility, it was shown that the value of the perceived quality increment from home-quality NTSC to studio-quality NTSC was substantially higher than the increment from studio-quality NTSC to studio-quality 1125-line HDTV. (See W.R. Neuman, "The Mass Audience Looks at HDTV: An Early Experiment," NAB, Las Vegas, 11 April 1988.)

³For those who believe in the effectiveness of the free market, this is an excellent place to make the case. If fiber, for example, is the best way to distribute TV, then it will come to pass automatically, and not by making current telephone subscribers pay for it whether they want it or not. (NY Times, 9 June 1992, p 1.)

⁴In Britain, 4 channels are used from any one transmission site out of 44 allocated, which is a poorer ratio than in the US. The British claim that this is because their interference standards are higher than ours, and because they make more extensive use of low-power fill-in transmitters.

number 68 using different kinds of source and channel coding. If, in fact, the current proposals make it possible to give every current broadcaster an extra channel for HDTV and work properly in every other respect (By no means has this yet been demonstrated.), then, when NTSC goes off the air and current channels revert to the Commission's inventory, 34 channels might be enough to provide as much service as we have now. If single-frequency networks are used, then 20 allocated channels would give us 20 independent services at every location in the country. Intermediate levels of efficiency would be provided by other arrangements discussed below.

The Proposed Transmission Technologies

In order to transmit symbols at the required rate,⁵ all of the proposed systems use adaptive equalizers to cancel echoes and frequency distortion. Such equalizers were originally developed for digital transmission through telephone networks, where the frequency response is fixed or slowly changing. Terrestrial broadcasting is an entirely different environment, with more frequency distortion, more noise, and, in some cases, rapidly varying echoes.⁶

To combat noise, which produces errors in digital transmission, and to improve the data rate at a given raw error rate, a combination of trellis coding and Reed-Solomon coding is used. The former regains some of the channel capacity lost due to using digital (rather than analog) transmission. The second corrects errors by adding check digits. Interleaving (a form of scrambling) is used to randomize burst errors and make them more correctable. About 30% of the theoretical channel capacity is devoted to error correction. The net result is increased throughput, lower error rate, and an extremely sharp threshold. In two of these systems, a fraction of a dB takes the image from perfect to absent. The other two have two thresholds, so that the abrupt shifts are from perfect to "viewable" and from viewable to absent. At the boundary of the service area, in view of the sharp threshold, very slight changes in conditions, such as those due to moving vehicles and shaking trees, or even due to changing scene content in an interfering NTSC signal, are likely to produce erratic reception.

These error-correction methods were also developed primarily for wired systems. They can nevertheless be used successfully in DBS and fiber service, where operation well above the threshold is the norm. They may be applicable to cable, although the use of numerous signal splitters and the resulting nonuniform signal level may reduce efficiency.

Alternative Transmission Technologies

There are very few digital terrestrial broadcasting systems in use anywhere in the world, so there

⁵The Nyquist theorem states that the maximum symbol rate is twice the bandwidth. To achieve this rate without interference between successive symbols, (intersymbol interference) the channel must be, in effect, an ideal band-pass filter, i.e., to have a flat frequency response across the used portion of the channel, typically about 5 MHz. Echoes are a form of frequency distortion. Within limits, the actual frequency response of a channel can be made ideal by using a correction filter whose parameters are dynamically adjusted for the particular situation.

⁶None of the proponents has given any data on the noise performance of the equalizers — either their performance in the presence of high noise levels or their effect on the SNR of the equalized signal. At least under some conditions, one would expect a substantial reduction of SNR as a result of cancelling strong positive echoes. There is also a question about the response time under noisy condition. GI and MIT have given some data on the magnitude of echoes that can be cancelled. It is the author's opinion that the projected performance is inadequate for use with SFN. (See below.)

is little actual experience to guide the system designer. One such system is the Joint Tactical Information Distribution System (JTIDS) in use by the military for communicating among ships, planes, and ground stations. Although JTIDS is not classified, there seems to be no regularly published information available. Much of the data to be handled is numerical, so digital transmission is natural. Voice service is also available. Spread spectrum is used for protection against multipath and for encryption. The data rate as compared to the bandwidth is much lower than needed for HDTV transmission in 6 MHz.

Another possibility for channel coding is to use systems with a soft threshold in order to raise the spectrum efficiency. Thus far, systems of this type have not been field tested, so it is not possible to say that their performance has been fully proven. They are described in Appendix 1.

Although not yet in commercial operation, a fully tested system, intended originally for digital audio broadcasting, to replace FM, is orthogonal frequency division multiplex (OFDM).⁷ OFDM is inherently immune to multipath, both fixed and moving, (the echoes are actually constructively added) and does not make use of automatic equalizers. The basic principle is the division of the signal into a large number of subchannels so that the symbol length in each subchannel is longer than the time-spread of the multipath. Having actually been converted to hardware, it appears to be no more complex than the US proposals. It also can be made to have excellent rejection of PAL or NTSC interference. The tests so far have been all-digital, so that any of the proposed source-coding systems could be used with OFDM channel coding. However, OFDM can also be used with analog or hybrid schemes, opening up additional possibilities, such as a soft threshold.

Although papers on OFDM have been presented in the US, few Americans seem to know about it or understand its significance. For this reason, the system is explained in greater detail in Appendix 1.

Closely related to OFDM is the concept of single-frequency networks (SFN). The immunity to multipath in OFDM makes possible a cellular network of low-power transmitters, *all operating on the same frequency*. The array of cells defines the reception area of a station, which may be of any size and shape. Contiguous reception areas can use the same frequency for different programs. SFN has also been field tested with very good results. With this system, the highest possible spectrum efficiency can be achieved; no more channels need be allocated than are used in any one reception area.

Relationship of These Matters to the Testing Program

The Second R/O, NPRM specifically asks for comment on the Advisory's Committee's judgment⁸

⁷OFDM has been under development in Europe at least since 1987. Its application to TV is currently being studied by a number of groups. An example of the work being done in Germany is given in Appendix 2 and of the Scandinavian project (HD-DIVINE) in Appendix 3. An international group call dTTb (digital terrestrial television broadcasting) is also at work. The plan is based on work done at NTL/ITC (the old IBA) called SPECTRE. Members of the consortium are from France, UK, Italy, Germany, and the Netherlands, and include most of the major companies and laboratories in Europe. There is a project at CCETT called STERNE. Thomson CSF has been studying this problem for a number of years and carried out a successful field test in the US in December 1990. Work is also going on at the CBC in Canada.

⁸Fifth Interim Report, 24 March 1992, p 19 and Appendix F.

that the currently proposed systems adequately represent the state of technology. A reading of the pertinent sections of the report shows that only compression technology, and not transmission technology, was reviewed.⁹ However, as discussed above, it is just in the area of transmission technology that the proposed systems are most suspect, and lag the most behind work already done and being continued, in Europe. While it is true that none of these advanced systems has been presented for testing, it would seem not in anyone's interests to disregard work so pertinent to new TV systems for this reason alone.

It can readily be seen that OFDM/SFN, with its very high spectrum efficiency, excellent protection against NTSC interference, reliability in the presence of severe multipath, and the benefit of extensive field testing, (far more than the US proposals will have, even *after* the planned field test) is very much superior to the channel-coding systems proposed for use in the US. To limit our choice to these systems would seem to guarantee an inferior system, both for our own use and for possible export. However justified the Advisory Committee's judgment, at the time it was made, that the proposed systems adequately represent the state of the art, it is not justified now.

Receiving Antennas

Another indication of the price that will have to be paid for using what amounts to telephone-line transmission technology rather than a more modern broadcasting system, such as OFDM, is the type and cost of antennas that will be required for home receivers. Since the adaptive equalizers of the proposed systems cannot cope with unlimited echoes, highly directional antennas with good front-to-back ratios are required. If all the stations to be received are not in the same direction, then rotatable or multiple antennas must be used. On the other hand, with OFDM/SFN, simple omnidirectional antennas are sufficient since transmissions come from all sides and the "echoes" are constructively added. With OFDM without SFN, antennas such as used with NTSC would be appropriate.

An educated opinion as to what kinds of antennas are required for various data rates, even with OFDM, is given in the following table. No such estimate has ever been publicly made for the US systems.

Efficiency (bit/s per Hz)	Receiver Installation	Display Resolution
1	Mobile	MAC (-4:2:0)
2	Portable	Enhanced
3	Fixed antenna	Higher (HD-MAC ?)
4	Fixed antenna (with signal equalisation?)	-HDTV
5	Adaptive antenna? Practical?	HDTV

Table 1 Possible Trade-offs Between Modulation/Channel Coding Efficiency, Receiver Installation and Display Resolution

From a paper by N. K. Lodge of the Independent Television Commission, Winchester, UK. Multiply the efficiency by 5 to get the approximate transmission rate in Mbits/sec in a 6-MHz channel.

⁹In view of the general inattention in the US to this matter, the fact that transmission technology was omitted from consideration is not surprising.

Conclusions and Recommendations

It is clear from the foregoing that any system based on the current proposals or any combination of them is likely to be obsolete before deployment. As intensive European work continues, we can expect the American developments to fall even further behind. Aside from the primary factor of spectrum efficiency, reliability is likely to be higher and antenna cost lower with an OFDM/SFN system such as described above. The main fault for this situation lies not with the system proponents but with the assumption that if a hardware contest were held, the best possible systems would necessarily be put forward. Given the sorry state of the US consumer-electronics industry, together with the very short time scale for designing and building very complex hardware, this was never probable. Events have shown that the assumption, if ever right, is now incorrect.

The question before us is what to do to correct the situation — to find a solution for terrestrial broadcasting that will truly represent the state of the art, and, as such, will serve us well for many years. A first step, in view of the lack of understanding in the US of the European work in digital broadcasting, is for all parties to inform themselves of these activities. One way to do this would be to organize a conference and to invite the leading European researchers to present their results. Another way would be to organize a tour of American researchers to visit the various European laboratories to inspect the work now going on. A third possibility is for the Commission to appoint a committee, including Commission technical staff members, to study the work and to make a recommendation.

A second step is to recognize that, given the state of the consumer-electronics industry, the best route to a good system is cooperation rather than competition. Three of the four digital-system proponents have already made a profit-sharing agreement, so that a basis for cooperation has already been laid. The fourth, through its member North American Philips, probably has the most knowledge about OFDM. If this group were to pool its talent and other resources, and be willing to listen to suggestions from nonmembers, a good result may be expected in several years' time.

A final step is to remove the exclusive burden of testing systems from the shoulders of the industry volunteers who are now supporting ATTC. The benefits of a good solution will be broadly distributed over a much larger group. For example, the computer industry, which has made such an issue over interoperability (which would be good for everyone, if done right) ought to contribute. Some jawboning on the part of the Commission might be sufficient, but, if not, some federal financing, perhaps through NIST, would seem appropriate.

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OFDM and Single-Frequency Networks:
Attaining Greatly Improving Spectrum Efficiency in TV Broadcasting

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The opinions expressed herein are those of the author only.

Abstract

Orthogonal frequency-division multiplex (OFDM), originally developed in Europe for digital audio broadcasting (DAB), is a channel-coding method that offers complete immunity to the effects of multipath (ghosts) up to a certain time-spread of the echoes. This limit is a design parameter of the system, and can, in principle, be made as large as desired. OFDM does not utilize automatic channel equalizers, the usual method of ghost cancellation. The system has been implemented in hardware and successfully field-tested in Europe, Canada, and the US.

Single-frequency networks (SFN) can be used to take advantage of the multipath immunity of OFDM to gain a very large increase in the spectrum efficiency of terrestrial broadcasting. With this method, the receiving area (or just its outer region) of a TV or radio station is filled with a cellular-like network of low-power transmitters, *all operating on the same frequency*. Each receiver "sees" a small group of time-displaced signals, which have the characteristics of ghosts. Since OFDM, in effect, adds up the ghosts to produce a single undistorted signal, perfect reception is assured. The service area of each station is now delineated by the location of the transmitters; there are no taboo channels, at least due to cochannel interference. If, say, 20 programs were to be made available in each locality (market), then only 20, rather than the current 68, channels need be reserved for television.

Spectrum Efficiency

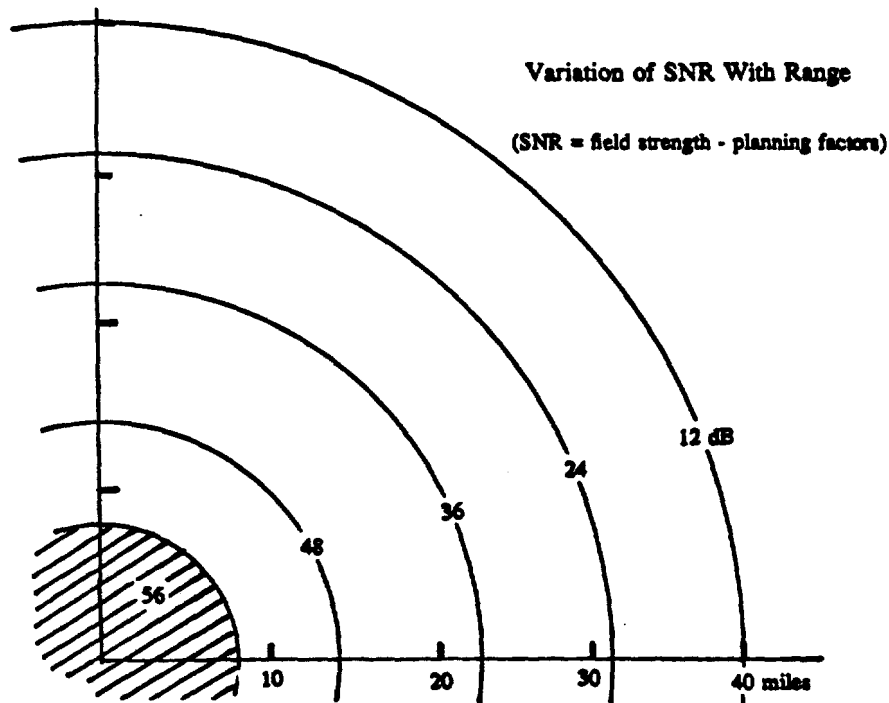
Since there are more demands for spectrum than there is spectrum available for assignment, using what there is in the most efficient manner must have a high priority with regulatory authorities. A qualitative way to define high spectrum efficiency is the most TV service for the smallest frequency allocation. A more quantitative definition is the the number of different programs of a given technical quality available to each viewer within a given overall spectrum allocation. We now get only 10 to 20 programs for an allocation of 68 channels because of taboos and because of the minimum required geographical separation of stations on the same channel.

It is clear from the foregoing that raising the ratio 20:68 is as important in achieving high spectrum efficiency as is getting the highest possible quality in 6 MHz.

The Need for Soft Thresholds with Centralized Transmitters

Another aspect of spectrum efficiency has to do with optimizing the image quality at each receiver, given the local CNR. The theoretical (Shannon) channel capacity is proportional to the product of bandwidth and CNR in dB. In analog systems, the higher CNR at closer-in points results in better quality pictures. This is an inherent property of analog transmission and does not require any special coding. It is effective because programs are viewable at a wide range of quality. They remain viewable even when the CNR is very low, as long as the audio remains adequate. Conventional digital systems have much sharper thresholds, so that no service at all is provided below a certain CNR, and the quality does not improve once above the threshold.¹

Some idea of the magnitude of this effect is apparent in the Figure. This shows the contours of constant SNR in the receiving area of a centrally located transmitter with an antenna height of 1350 feet.² The close-in channel capacity is nearly five times that at threshold. A coding system that would allow the receiver to recover an amount of data proportional to the actual channel capacity at its terminals and that would produce image quality proportional to the received data rate could provide better quality, on average, at much less bandwidth per channel, than systems that deliver the same data rate and picture quality everywhere.



¹The ATRC and the AT&T/Zenith proposals have two thresholds, so that a high-quality service is provided above one threshold and a "viewable" picture above the second (lower) threshold, in these cases 5 to 6 dB apart. While this is a step in the right direction, the two thresholds are not very far apart on the ground, and no advantage is taken of the much higher capacity closer in. It should be noted that the FCC has never required the same quality to all receivers, nor is that the present situation with NTSC.

²Rather conservative planning factors were used in producing this diagram. With the most optimistic factors, the radii of the higher contours would be moved out somewhat. In no case would they extend beyond the radio horizon of 52 miles. Note also that this transmitter, operating at a power level 12 dB below a nearby cochannel NTSC station as needed for interference purposes, does not provide service beyond the NTSC grade-A contour.

A soft threshold can also be achieved with hybrid modulation, in which analog data rides on top of digital data. For example, when using the discrete cosine transform with adaptive selection of coefficients as a principal bandwidth-compression method, the information about which coefficients have been retained must be transmitted error free, while the amplitudes of the coefficients can have some noise added without catastrophic effect on quality. It is natural, therefore, to transmit some data digitally and the rest analog, particularly as the analog transmission achieves much higher transmission efficiency than the digital.³

There are other modulation methods, some digital, that can achieve a stepped (rather than continuous) increase in transmission rate with CNR. [1] To be useful, they must be combined with multiresolution source coding, so that the additional data that is recovered at higher CNR can be constructively used to increase picture quality. The author is working on a spread-spectrum system. It is hoped that this system will have many of the advantages of OFDM and yet have a soft threshold.

OFDM

The basic principle of this system [2] involves dividing the spectrum of the signal into a large number (hundreds) of components so that the symbol length of each component is longer than the temporal spread of the echoes. In the DAB scheme, the symbol duration is 80 microseconds, of which 64 are active and 16 ignored. This absolutely guarantees that, up to a time spread of 16 μ sec, all echoes arrive within one symbol period, where they are added, rather than interfering with each other. Rapidly changing echoes are treated the same way as fixed echoes. No channel equalizer is required. Certain frequency ranges can be left unused to gain higher immunity to NTSC interference.

OFDM is not a competitor for PSK or QAM. These, or any other known modulation methods, can be used for the separate carriers. OFDM is best thought of as a multicarrier channel-coding method specifically designed to deal with the problem of multipath distortion.

The implementation of the system is quite practical. Signals in adjacent channels are orthogonal to each other; no guard bands are needed. The inverse Fourier transform is used to separate components at the receiver. Since the multiple received signals are constructively added, there is no need for highly directional antennas.

It is important to note that OFDM and its theoretically expected operation have been fully proved out in field tests in Europe and Canada. (A successful field test by Thomson CSF in the US in Dec. 1990 has only recently been revealed, and there was a Scandinavian demonstration at IBC 92.) It is a thoroughly practical system and will almost surely be used for digital audio broadcasting in Europe, ultimately to replace FM. Work on the application to TV is underway, some field testing already having been done.

³QAM systems normally achieve transmission rates at least 9 dB below the Shannon limit. Trellis coding can be used to get back some of this lost efficiency. This method is typically combined with error correction, such as Reed-Solomon coding. The higher efficiency necessarily leads to an extremely sharp threshold.

Motivation for OFDM

The main reason for the use of OFDM for DAB is the multipath immunity and the resultant high reliability without resort to automatic channel equalizers, particularly when the receivers are themselves mobile. The multipath immunity has proved so effective that it is possible to use fill-in retransmitters in areas shadowed from the main signal by buildings or mountains. These retransmitters are fed from nearby receiving antennas and operate on the same frequency. At the boundary of reception areas of the main and retransmitted signals, the two appear to be echoes and are successfully dealt with by the receiver. In the test in Montreal, such a retransmitter was installed in a vehicular tunnel with excellent results. OFDM can be used equally well with digital, hybrid, or analog transmission.

Single-Frequency Networks

In an extension to the retransmitter idea, all or a large part of the reception area of a station can be served by a cellular array of low-power transmitters, all operating on the same frequency. [3] Another, centralized, portion of the area can be served by a medium-power transmitter or even by satellite transmission with a small footprint. The cellular transmitters derive their signals from each other, from the main signal (where there is one), or by wire. The size of the cells is limited by the temporal spread for which the system is designed. The argument for soft thresholds has much less urgency with SFN.

This arrangement has the potential to raise the above-mentioned ratio, 20:68, to 20:20, as it completely eliminates cochannel interference. It also facilitates colocation for stations on adjacent channels (they can share the same cellular sites), so that adjacent channels can be used in the same city. It is such a powerful method of raising spectrum efficiency that it merits at least very careful examination by regulatory authorities.

SFN does require some additional capital expenditure by current broadcasters. However, the total transmitted power is much less than at present, and it has many other benefits, such as precisely defined service areas. It can be introduced station-by-station and city by city. In rural areas, or in small cities located far from other cities, it need never be used. Its overwhelming advantage is the fact that we can have at least as much TV service as today and still give back hundreds of Megahertz for other wealth-producing activities.

It is most unlikely that the multipath performance required for the successful operation of SFN can be achieved with adaptive equalizers. A channel-coding system that actually adds up the several received signals, such as OFDM, seems required.

The most recent work in Europe on OFDM and SFN is described in [4-9]. The Scandinavian system described in [7] was demonstrated at IBC 92. The Thomson CSF system described in [8] was field-tested in the US in Dec. 1990. It is not clear why the results were not revealed until IBC 92. Note that OFDM is not a new idea; some history is given in [10-11].

Conclusions

Spectrum efficiency is a major concern of regulatory authorities. Its achievement with centralized transmitters requires a soft threshold, so that picture quality can be optimized at each receiver. Even higher spectrum efficiency can be achieved with single-frequency networks using a cellular array of low-power transmitters, all operating on the same frequency. With such an arrangement, the 68 channels allocated for TV might be reduced to 20 without any sacrifice in the number of programs available to each viewer.

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All these references are available from the author.

HDTV-T

- Digital terrestrial broadcast of HDTV -

Description of joint research project

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1. Background and Scope

Digitization of all video services has become a worldwide objective. This can be explained by the introduction of digital networks like ISDN or B-ISDN or digital storage media (CD-ROM, digital VCR) on the one hand and by the improved possibilities of large scale integration on silicon on the other hand.

Digitization of High Definition Television takes already place on the production (digital VTR, digital post production) and receiver (HD-MAC decoder) side. Only for transmission analogue forms have been used up to now because of the properties of existing transmission channels and because of compatibility constraints. Therefore the introduction of MUSE and MAC/HD-MAC is planned in Japan and Europe respectively.

However, since the middle of the 80th digital solutions for terrestrial and satellite transmission are discussed as well. A first recommendation for digital satellite transmission over broadband channels has been formulated by CCIR in 1991.

The work actually carried out in the U.S. is motivated by the rules given by the Federal Communication Commission (FCC), postulating that HDTV has to be transmitted within 6 MHz channels and by the fact, that conventional analogue transmission systems like PAL, SECAM or NTSC do not use the available channel capacity efficiently and are very sensitive to distortions. The problem of compatibility is solved by the simulcast approach, where the HDTV-program is transmitted in a down converted version over a normal NTSC channel.

Behind the background of these developments in the US, it becomes necessary for Europe, to start comparable investigations in order to acquire the specific know-how because in a long term digitization of all video services will take place anyway.

Motivated by the German Ministry of Science and Technology, a research project called "Digital Terrestrial Broadcast of HDTV - definition phase" has been started at the Heinrich-Hertz-Institut. This project lasting from April 1st, 1991 to March 31st, 1992, has been carried through in cooperation with the companies and organisations Deutsche Thomson-Brand (DTB), Grundig, ITT-Intermetall and ARGE Detecon/DLR. In this project the basis of HDTV-coding with 20...30 Mbit/s, of modulation techniques for terrestrial transmission and of network aspects have been studied. A main topic of the investigations was the scalability aspect with respect to compatible TV/HDTV transmission and graceful degradation.

A main result of the definition phase was the realization, that digital HDTV is feasible in principle, but that there remain a lot of unsolved problems and that there exists a clear difference between terrestrial networks in Europe and the U.S., which has a strong influence on introduction scenarios.

Therefore this project has the objective to carry through further theoretical investigation and simulations, to define a system suitable for terrestrial digital broadcast, to build up a hardware demonstrator for compatible TV/HDTV and to carry through field trials. Only by following this procedure it will be possible to

gain secure results which will enable the participants of this project to contribute in a well-founded manner to the development of digital terrestrial broadcast in Europe.

2. Scientific and technical objectives

It is objective of the project to investigate the possibilities of digital HDTV broadcast over terrestrial channels, satellite channels and broadband cable networks by means of theoretical analyses, computer simulations, hardware developments and field trials. Based on the results of this work it will then be possible to develop introduction scenarios for a digital TV/HDTV broadcast service and with it practical alternatives to today's systems.

Fig. 1 shows to block diagram of a complete transmission chain of a digital broadcast service. On the transmission side the video signal is first preprocessed and then fed into the source encoder. The resulting data rate has to lie in the range between 20 and 30 Mbit/s. The compressed data have to be protected against transmission errors by adding protection bits in the FEC encoder. Furthermore sound and sync signals have to be multiplexed into the data stream and a resulting bit rate between 30 and 40 Mbit/s has to be transmitted.

In the subsequent RF-modulator the digital data are transformed into a signal wave form which is suitable to be transmitted over the air. The bandwidth of this signal has to be in the range between 7 and 8 MHz. The mixer modulates the RF signal into an appropriate frequency band (e.g. UHF) and the signal can then be emitted.

For the satellite and for cable networks similar processing steps have to be performed, but the transmitter frequencies are different, i.e. 300 - 450 MHz for the cable.

On the receiving side the inverse processing steps have to be performed in opposite order. The baseband signal is obtained by passing through the mixer, the RF-demodulator, the demultiplexer, the FEC-decoder and the source decoder.

Furthermore the signals coming out of the FEC-decoder can be fed into a transcoding unit in order to be recorded on a VCR. Capability of signal recording is an important property of any TV system because without this feature no new service will be successful in the market.

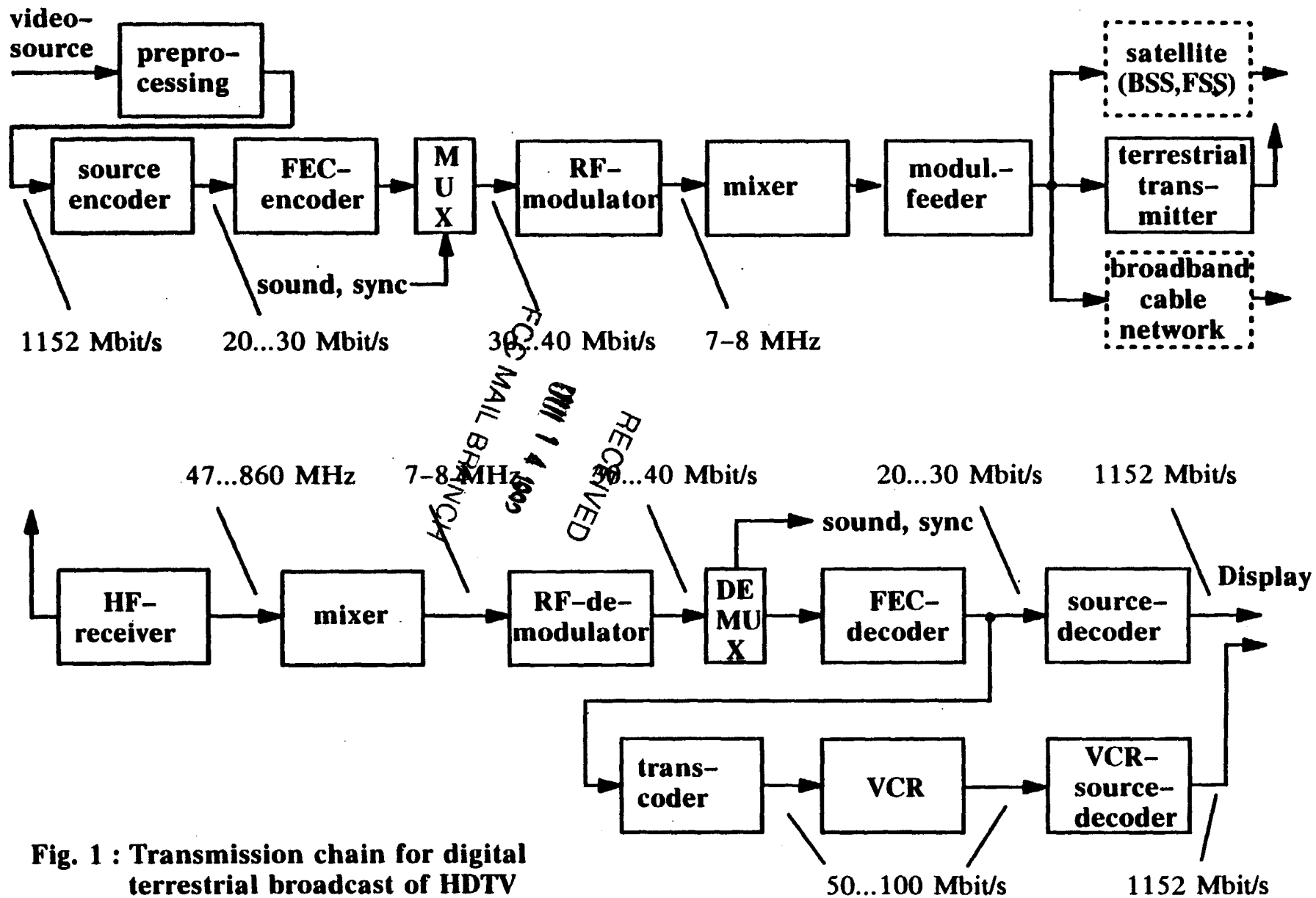


Fig. 1 : Transmission chain for digital terrestrial broadcast of HDTV

Based on this description the following topics will be investigated in the project:

- Video source coding (data compression)
- Transcoding for recording (VCR)
- Channel coding (error protection)
- Modulation
- Digital hierarchy (Personal Video, TV, HDTV)
- Other system aspects (audio, additional services etc.)
- Receiver aspects
- Specific VLSI components
- Demonstrator development
- Network aspects
- System trials (laboratory, field)
- System optimization

3. Timetable

The whole project is separated into three overlapping phases.

Phase 1 - System definition: 1.04.1992 - 30.6.94

- Digital hierarchy
- Source coding
- Channel coding
- Other system aspects
- Channel simulation
- Transcoding
- Receiver aspects

Phase 2 - Hardware realization: 1.01.93 - 31.12.94

- Hardware developments
- Specific VLSI components
- Demonstrator integration

Phase 3 - System trial and optimization: 1.07.94 - 31.12.95

- Laboratory trial
- Field trial
- System optimization

It is intended to complete the demonstrator hardware of the whole transmission chain until the first half of 1995.

4. Participants and cooperations

The following partners will be member of the joint project:

- Bosch-Forschungsinstitut
- DAB-Plattform (DAB)
- Telekom (FI/FTZ)
- DLR-Institut für Nachrichtentechnik - Oberpfaffenhofen (DLR/NT)

- Deutsche Thomson-Brandt (DTB)
- Grundig EMV
- Heinrich-Hertz-Institut (HHI)
- Institut für Rundfunktechnik (IRT)
- ITT-Intermetall (ITT)

Some of the partners are members of European research projects with related topics and the results obtained in those projects will be taken into consideration or the work of this project will be coordinated with those activities.

This concerns mainly the EUREKA project 625 (VADIS) for coding of TV and the RACE project dTTB for digital terrestrial TV-transmission, which is mainly focussed on modulation techniques and network aspects.

5) Project organization

The organization chart of the project is shown in Fig. 2. The project is lead by a steering committee, in which each of the partners is represented by one member.

There are four main working groups (WG1...WG4) dedicated to the following topics:

- System aspects
- Image compression
- Modulation
- Hardware

Furthermore ad-hoc working groups will be founded, in which topics of interest to more than one working group will be treated (e.g. channel coding) or in which side aspects (e.g. audio, additional services) will be investigated. The organization of the project is regulated by a cooperation agreement.

6) Contact address

Further informations can be obtained from:

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Swedish Broadcasting Corporation
RESEARCH AND DEVELOPMENT DEPARTMENT

WP V SC 061
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GT V4/MOD 164

DEVELOPMENT OF DIGITAL TERRESTRIAL HDTV IN SCANDINAVIA.

Public service television broadcasting in the Nordic countries basically relies on terrestrial transmitters. These will be used for a long time to serve a large proportion of the population. The introduction of HDTV would be very much facilitated by a system that suits terrestrial transmitters. Such a system can also be adapted to other transmission media, such as cable TV networks, TV satellites and broad-band networks. From the consumers' point of view it is also important to establish a future-proof system with a common type of receiver for all transmission media. Only a fully digital system complies with these requirements.

Swedish Telecom, in cooperation with Norwegian Telecom, Swedish Broadcasting Corporation, Digital Vision - DV Sweden AB and SINTEF DELAB in Norway, are therefore developing a experimental system for digital terrestrial HDTV. It will be used for field tests and demonstrations over terrestrial TV transmitters. The equipment is due for delivery by mid 1992 and is intended to be on display at IBC 92. The costs of the project are estimated at nearly SEK 20 million. Telecom Denmark is currently joining the project.

The project is managed by a Steering Group, chaired by the Swedish Telecom Radio (STR), with members from Telia Research AB (TRAB, the R&D subsidiary of the Swedish Telecom), the Swedish Broadcasting Corporation (SR) and the Swedish Television Company (SVT). A project leader has been appointed by TRAB.

The project is currently divided into three parts; Picture coding, Transmission and Network for digital terrestrial HDTV. Phase 1, wich primarily aims at implementing the experimental system for digital terrestrial HDTV, is accomplished in only one year.

The Picture coding Group studies and defines various aspects of the HDTV codec, such as

- * image format
- * basic algorithm
- * pre- and postprocessing
- * variable parameters, flexibility
- * refresh methods
- * effects of channel characteristics
- * degradation

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Software simulations of the codec are being done by TRAB and SR/SVT. The coding algorithm is based on hybrid DCT, and the bit-rate (including four sound channels) is about 24 Mbit/s. The hardware is built by DV Sweden under a contract with STR.

The Modulation Group draws on an extensive study of COFDM made by TRAB in 1991. At present TRAB and SR participate in this Group, but Telecom Denmark is presumed to join soon. The hardware is built by DELAB under a contract with STR with funding from the Research Institute of the Norwegian Telecom. The channel bit-rate is approximately 27 Mbit/s.

The Network Group works on a longer time-scale and is not directly involved in the experimental system. It is currently manned by STR and TRAB, but contributions are expected from Telecom Denmark.

Hardware demonstrations and field tests are expected from summer 1992 and onwards. No definite plans have yet been established, but live demonstrations of digital terrestrial HDTV to the EBU and other interested organisations could be envisaged during the autumn of 1992.

It is the hope of the participating organisations that this project will prove that digital terrestrial HDTV is viable and that it may stimulate further development, standardisation and introduction of such a system before the end of this century.